AD NUMBER

AD877791

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Administrative/Operational Use; Dec 1970. Other requests shall be referred to Naval Weapons Center, China Lake, CA 93555.

AUTHORITY

Naval Weapons Center ltr dtd 30 Aug 1974

NWC TP 5059

COPY 10

20

MECHANICS OF WAVE BEHAVIOR IN EXPLOSIVELY LOADED ROD

by

John S. Rinehart
ESSA Research Laboratories
for the
Research Department

ABSTRACT. High-speed photography (166,666 to 333,330 frames per second) has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA * DECEMBER 1970
93555

20

NAVAL WEAPONS CENTER

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

W. J. Moran, RADM, USN .... Commander

H. G. Wilson .... Technical Director

FOREWORD

The study described in this report is one of a series made as part of a continuing applied research program at the Naval Weapons Center in support of explosive ordnance problems.

The work was supported in part by funds under the Naval Air Systems Command Task Assignment A35-350/216/69 F17353501, and was performed by Dr. John S. Rinehart at the Environmental Science Services Administration Research Laboratories, Boulder, Colorado.

This report has been prepared primarily for timely presentation of information. Although care has been taken in the preparation of the technical material presented, conclusions drawn are not necessarily final and may be subject to revision.

Released by
JOHN PEARSON, *Head*
Detonation Physics Division
2 November 1970

Under authority of
HUGH W. HUNTER, *Head*
Research Department

NWC Technical Publication 5059

Published by....................................Research Department
Collation..............Cover, 9 leaves, DD Form 1473, abstract cards
First printing..................................220 numbered copies
Security classification..............................UNCLASSIFIED

BLANK PAGE

INTRODUCTION

When a solid cylinder is struck a sharp and strong blow on one end, the end of the cylinder generally suffers severe damage, appearing as if an internal axial explosion had blown it apart. Major damage is usually limited to a distance along the cylinder equal to about two or three cylinder diameters. A well-defined teardrop-shaped symmetrical plug forms in Plexiglas (Fig. 1) and a similar pattern of fracturing is observed in aluminum, steel, glass, and copper cylinders. The pattern is controlled principally by the geometry of the specimen rather than the material and scales almost perfectly with cylinder diameter.

Only a small fraction of the energy of the original blow remains in the cylinder, the rest being carried away by the pieces that fly off. This small remaining fraction moves down the cylinder as an elastic wave with rod velocity, $[E/\rho]^{1/2}$, where E is the Young's modulus and ρ is the density of the rod material.

Previous tests[1] with essentially point explosive charges (charges whose area of contact was very small compared with the area of the end of the cylinder), have shown that internally reflected and transformed stress waves can cause fracturing when they are focused and thus caused to interact.

The present study differs from previous ones in several respects. The entire end of the cylinder was covered with explosive so that the impulsive load acted simultaneously over a large area. The simple ray tracing techniques used before are inadequate to describe the wave interactions since the phenomena must now be treated as a diffraction problem. Damage is much more severe and the intensity of the elastic wave developed with the larger explosive is high enough to make visible the deformation produced during action of the wave. But most important, the present tests were monitored with high-speed photographic equipment up to framing rates of 333,330 per second. This made it possible to observe the actual formation of the fractures, the propagation of the waves generated by the explosion and subsequent reflections and, from these observations, develop a better understanding of the genesis of rod waves.

[1] Rinehart, John S. and Jean-Jacques Prompsy. "On Axial Fractures Produced by Explosively Induced Shocks in Plexiglas Rods Simulating Drill Bits," SOC PETROL ENGINEERS, J (September 1962), pp. 207-10.

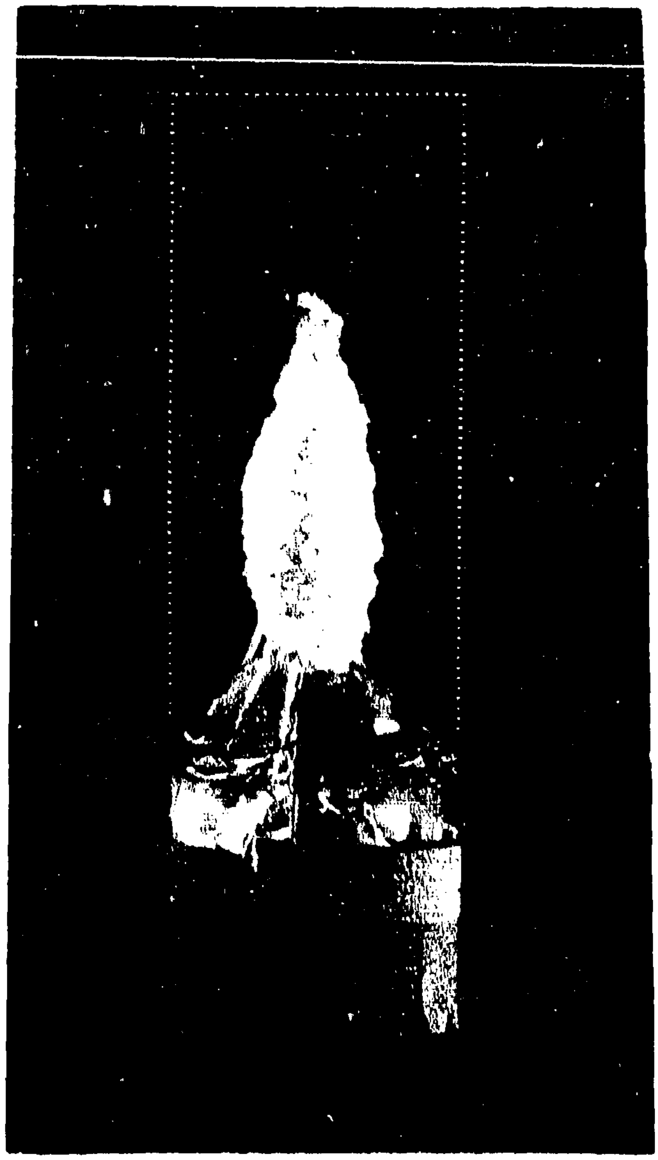

FIG. 1. Plexiglas Cylinder Recovered After Detonation of Explosive on Its Upper End. Dotted line is contour of original cylinder which measured 1.5-inch diameter.

EXPERIMENTAL WORK

A solid cylinder of Composition C-4 explosive was affixed to the end of a cylinder of the same diameter as illustrated in Fig. 2, detonated, and the pieces recovered and reassembled insofar as was possible. Both Plexiglas and aluminum cylinders were fired, with diameters ranging from 1/2 to 3 inches. The cylinders ranged from 12 to 6 inches in length, depending on diameter. Dimensions of all the specimens are listed below. Three of each size were fired. The specimens were long enough that reflections from the far end did not influence breakup near the end in contact with the explosive although some spalling occurred near the far end.

Material	ℓ (in)	L (in)	D (in)
Plexiglas	6.0	12.0	3.0
Plexiglas	4.5	12.0	2.25
Plexiglas	4.0	12.0	2.0
Plexiglas	3.0	9.0	1.5
Plexiglas	2.5	9.0	1.0
Plexiglas	2.0	6.0	0.5
Aluminum	5.25	12.0	2.63
Aluminum	4.0	12.0	2.0
Aluminum	3.0	9.0	1.5
Aluminum	2.5	9.0	1.0
Aluminum	2.0	6.0	0.5

High-speed color photographs were taken at the Naval Weapons Center of three of the 3-inch-diameter Plexiglas specimens using a Cordin camera operating at either 166,666 or 333,330 frames per second. The experimental setup is sketched in Fig. 3 and a single frame is reproduced in Fig. 4. Two argon bombs were used to light the specimen.

FRACTURE PATTERN

The pattern of fracture in a typical Plexiglas specimen is sketched in Fig. 5 and a cross-sectional aluminum specimen is shown in Fig. 6. None of the material above A in Fig. 5 could be recovered. This point lies about one cylinder radius from the original end of the cylinder and is the upper terminus of a teardrop-shaped region. In aluminum, this region is heavily internally fractured (Fig. 6) but has not separated from the parent cylinder. With Plexiglas, the region is also heavily internally fractured but it forms a cohesive plug which usually completely separates from the rest of the cylinder (Fig. 1). The stem of the Plexiglas plug, nearest A in Fig. 5, is completely fused, indicating that it was heated above the melting point during passage of the stress wave.

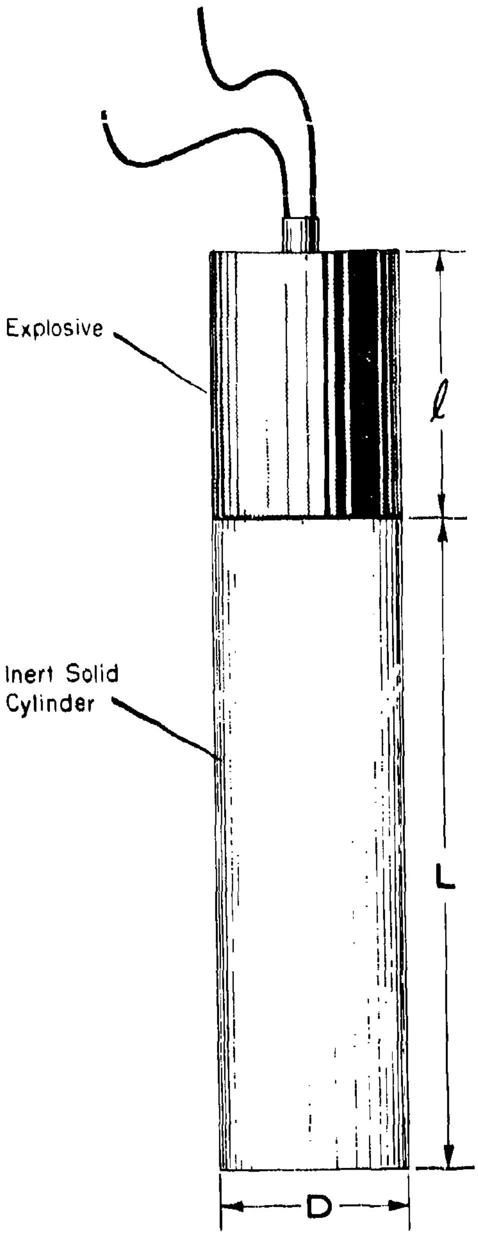

FIG. 2. Explosive-Cylinder Arrangement.

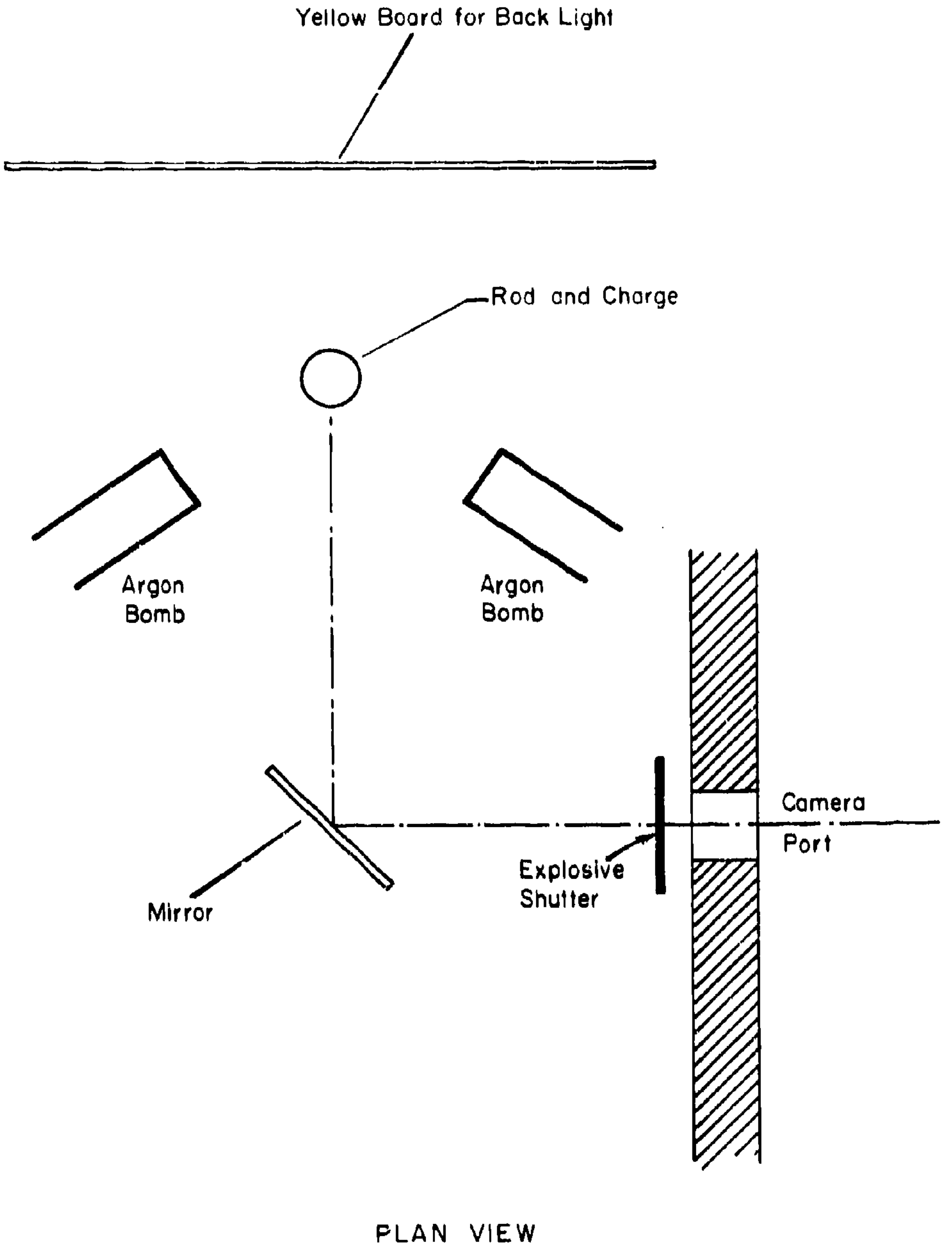

FIG. 3. Experimental Arrangement for High-Speed Photography.

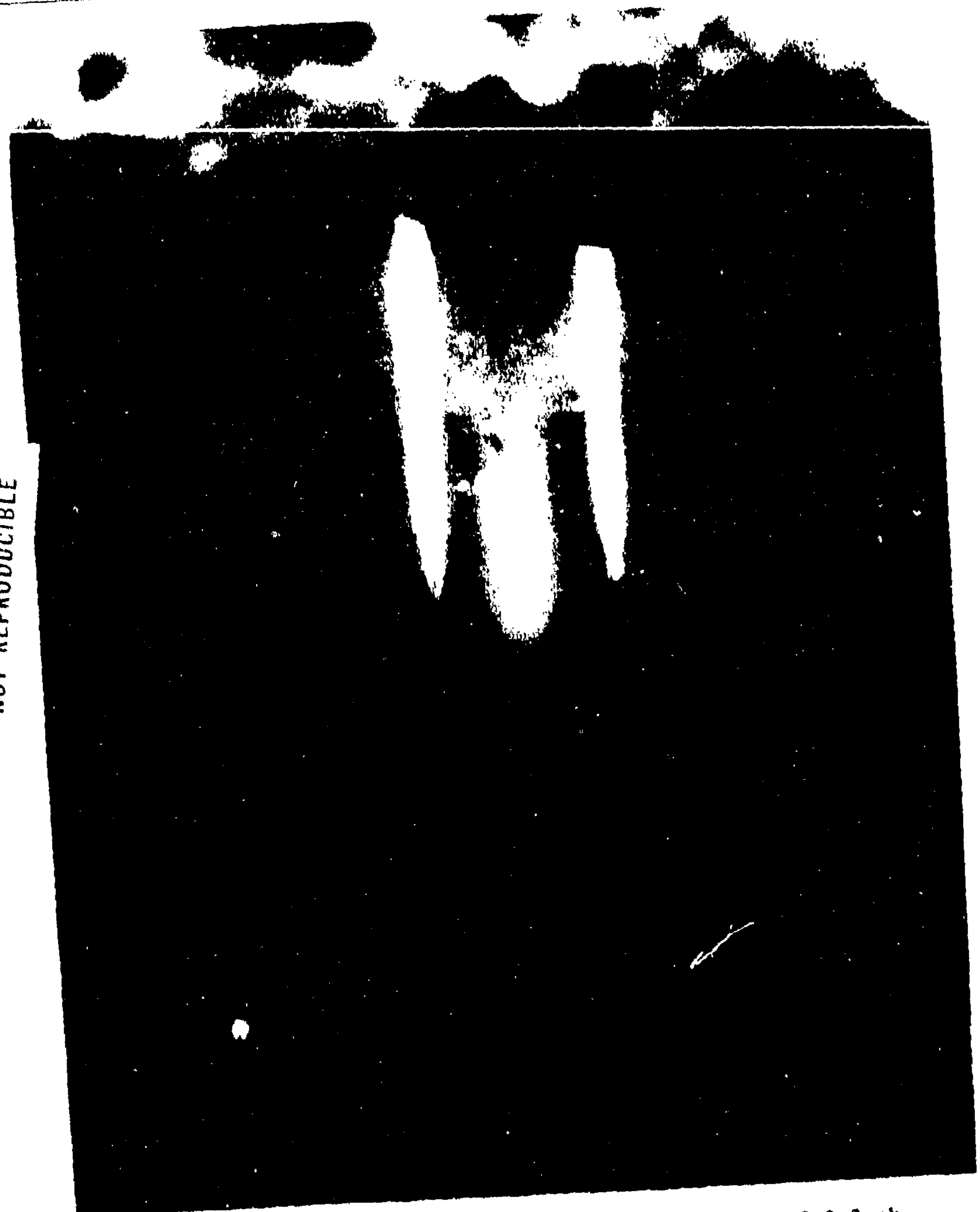

FIG. 4. Central Fracturing Propagating Along Axis of 3-Inch-Diameter Plexiglas Cylinder. Interframe time - 6 μsec.; reproduction too poor to show wave. Bright vertical lights are direct reflections of argon bombs.

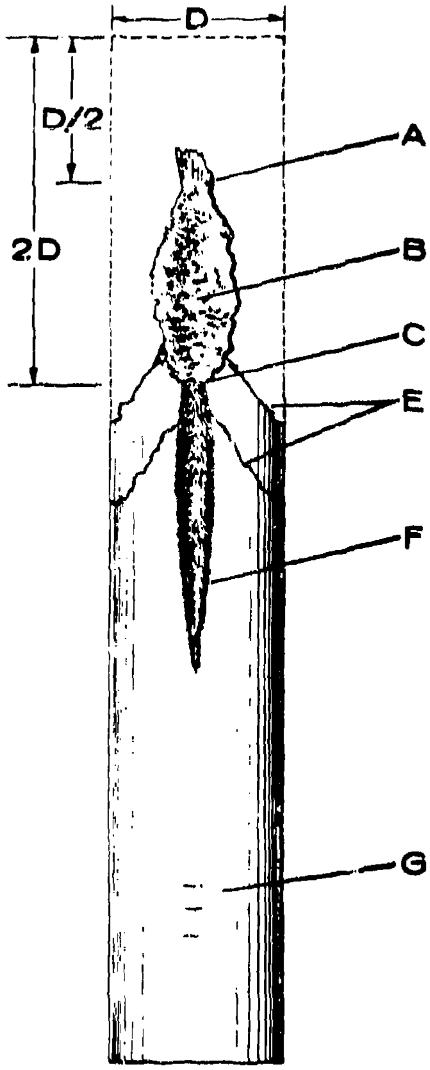

FIG. 5. Sketch of Typical Fracture of Plexiglas Cylinder.

FIG. 6. Cross-Sectional View of 1.5-Inch-Diameter Fractured Aluminum Cylinder. White dot labelled A is 3 inches from original top end of cylinder.

Below A, the diameter of the teardrop region or plug increases, reaching a maximum at B of about one cylinder radius. Then about halfway through its length, its diameter begins decreasing, becomes zero and terminates at C, about two cylinder diameters from the top end of the cylinder.

In both aluminum and Plexiglas, the teardrop region or plug is heavily shattered as is evident in Fig. 6 and 7. In Figure 7, which is the cross section of a Plexiglas plug from a 2-inch-diameter cylinder, the fractured pieces have recemented themselves solidly--probably through fusion. The fracturing is layered, forming a rough chevron pattern symmetrical around the axis of the cylinder.

The smooth curved fractures at E in Fig. 5 are quite prominent in the photograph of Fig. 1 and appear as if they were formed when large chunks bending radially outward, broke off. Such an S-shaped smooth fracture is a common feature of a bar broken by a static bending force.

A more mildly fractured central region, F in Fig. 5, lies below the plug and extends down one to two cylinder diameters. This region consists of numerous preferentially oriented microfractures nestling relatively close to the axis.

In the G region, there are usually a few horizontal spall fractures. The extent of this type of fracturing is strongly dependent on conditions at the far end, especially whether the rod rested on a firm or loose footing. No systematic attempt was made to control this condition during the experiments.

WAVE PATTERN

The pattern of waves that might reasonably be expected to develop in a solid rod impulsively loaded on one end is fairly easy to define from simple geometrical considerations. In the left hand drawing of Fig. 8, the detonation front is shown moving down through the explosive, reaching the end MN of the solid cylinder and subjecting it suddenly to an intense compressive load.

A sharp fronted pure dilatational compressional wave, AB in the center drawing, is set up which moves down the cylinder with dilatational wave velocity, c_1, given by

$$c_1 = [(\lambda + 2G)/\rho]^{1/2}$$

where ρ is the density of the material and λ and G are its Lamé's elastic constants. At the same time the free surface of the cylinder begins to expand, the expansion rapidly works its way inward, establishing a tensile release wave. The center drawing of Fig. 8 depicts the state of affairs at the instant the expansion has progressed about halfway through the cylinder. The expansion wave moves with the velocity c_1 of dilatational waves and converges toward the axis, amplifying tremendously the magnitude of the expansive tensile stresses. Theoretically, these

FIG. 7. Fractured Plexiglas Plug Formed in a 2-Inch-Diameter Cylinder.

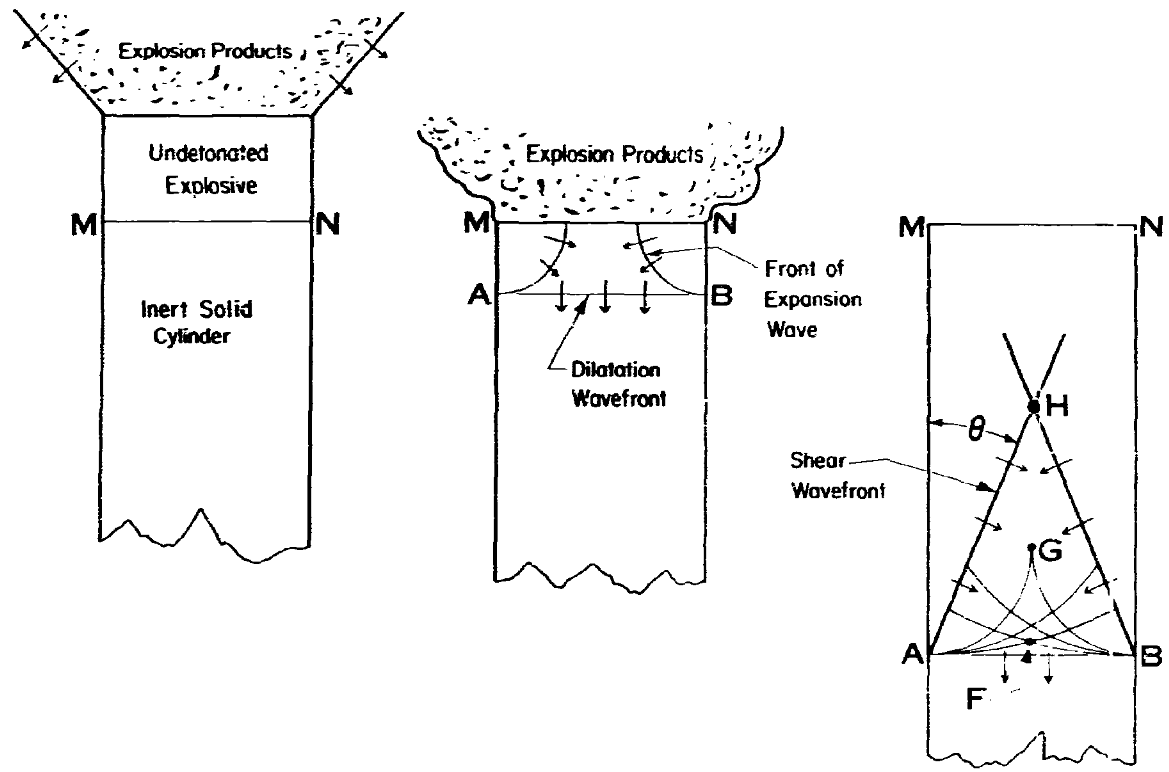

FIG. 8. Stages in Development of Wave Pattern in Upper End of Cylinder.

stresses could build up to an infinite value along the axis. Unfortunately, the problem of expressing them in analytical form has thus proved intractable. This is mainly because the wave does not have a true coherent front in the sense that a Huygen's envelope can be constructed. The region in which expansion has been felt can be thought of as one containing an infinite number of wavelets, each having originated successively at a new point along the surface of the cylinder as the parent wave progresses downwardly. While each wavelet could be presumed to have no energy, the combined effect of all the wavelets certainly extracts energy from the parent wave. Qualitatively it is seen that this process will generate a kind of wave of expansion having its highest stress gradients when moving across the end section MN with the gradients lessening as convergence occurs further along the cylinder. A few cylinder diameters down the cylinder, its entire cross section is in more or less uniform motion and differential lateral stresses will have largely disappeared. This is the situation in the right-hand drawing of Fig. 8. The conical region (AFB) is the only region thus far unaffected by the expansion. As the original wave progresses, the region becomes flatter; the point F approaching closer to AB. The greatest concentration of tensile stress is at point G.

Physically, the only way to initiate and maintain the lateral motion associated with the expansion and at the same time satisfy boundary conditions and momentum and energy considerations is to generate a relatively strong shear wave. The envelope of the front of this shear wave is the cone AHB (Fig. 8) whose outside boundary is dragged along by the expansion wave. The shear wave, as well as the expansion wave, can only derive its energy from the parent compressive wave; thus the intensity of the wave front AB is being continually degraded. Eventually the front disappears altogether, merging into F after having given up all its energy to the other two waves.

The angle θ (Fig. 8) that the shear wave front makes with the surface of the cylinder is controlled by the respective velocities c_1 and c_2 of of the dilatational and shear waves, being given by

$$\sin\theta = c_2/c_1$$

where

$$c_2 = [G/\rho]^{1/2}$$

The shear wave is highly convergent and high-stress gradients can be expected to develop, especially along the axis. The shape of the cone AHB should not change appreciably as it moves down the cylinder.

The first phase of the transformation of the original pure dilatational wave into a rod wave is now virtually complete. The whole cross section of the cylinder in the neighborhood of the disturbance is moving laterally as well as longitudinally. The situation has changed from one

of plane strain at the end MN to one of plane stress in a cross section lying two or three cylinder diameters down the cylinder. The energy will now travel with a velocity c_R, given approximately by

$$c_R = [E/\rho]^{1/2}$$

For most solids, c_R is about 20% less than the dilatational wave velocity c_1. The only remaining redistribution of energy will be that associated with reflection and re-reflection of the shear wave from the outer surface of the cylinder after transit across it. These reflections will generate new shear and dilatational waves which contribute in a very complex way to the distribution of energy in the rod wave. Usually, it takes about twenty cylinder diameters of travel for the rod wave to become stable.[2]

EVENT VELOCITIES

High-speed photographs make it possible to follow, in a quantitative fashion, the course of events and to establish the origins of the observed fracturing.

Progress of the original dilatational wave front and the front of the evolved rod wave is easy to trace by the deformations on the mirror-like surface of the Plexiglas cylinder. Fracture formation is also easily observable since the developing fractures are excellent light scatterers, making them clearly visible.

The data obtained from one series of photographs taken of a 3-inch-diameter Plexiglas specimen are shown in Fig. 9 as distance versus time plots. The framing rate was 166,666 frames per second. Two other series of photographs, one taken at 333,330 frames per second, are in substantial agreement with this series.

The upper curve (open circles in Fig. 9) describes the progress of the stress wave front. For about 7 1/2 inches (2 1/2 cylinder diameters) it moves with a velocity of 11,700 ft/sec. At about this point the velocity begins to decrease, and an inch or so down the cylinder a velocity about 20% lower (9,200 ft/sec) is obtained. These velocities correspond closely to recognized values, respectively, of the dilatational and rod velocities in Plexiglas. The reduction in velocity must certainly be a consequence of the transformation of the pure dilatational wave into a rod wave. The rod wave moves on down the cylinder, finally reaching the end at t = 100 μsec where it is reflected, and the reflected wave moving back along the cylinder with the same velocity.

The formation of the central fracture (solid circles in Fig. 9) is obscured by explosion products and peripheral shattering for about the

[2] Christie, D. G. "An Investigation of Cracks and Stress Waves in Glass and Plastics by High Speed Photography," SOC GLASS TECHNOL J, Trans., 36 (1952), pp. 74-89.

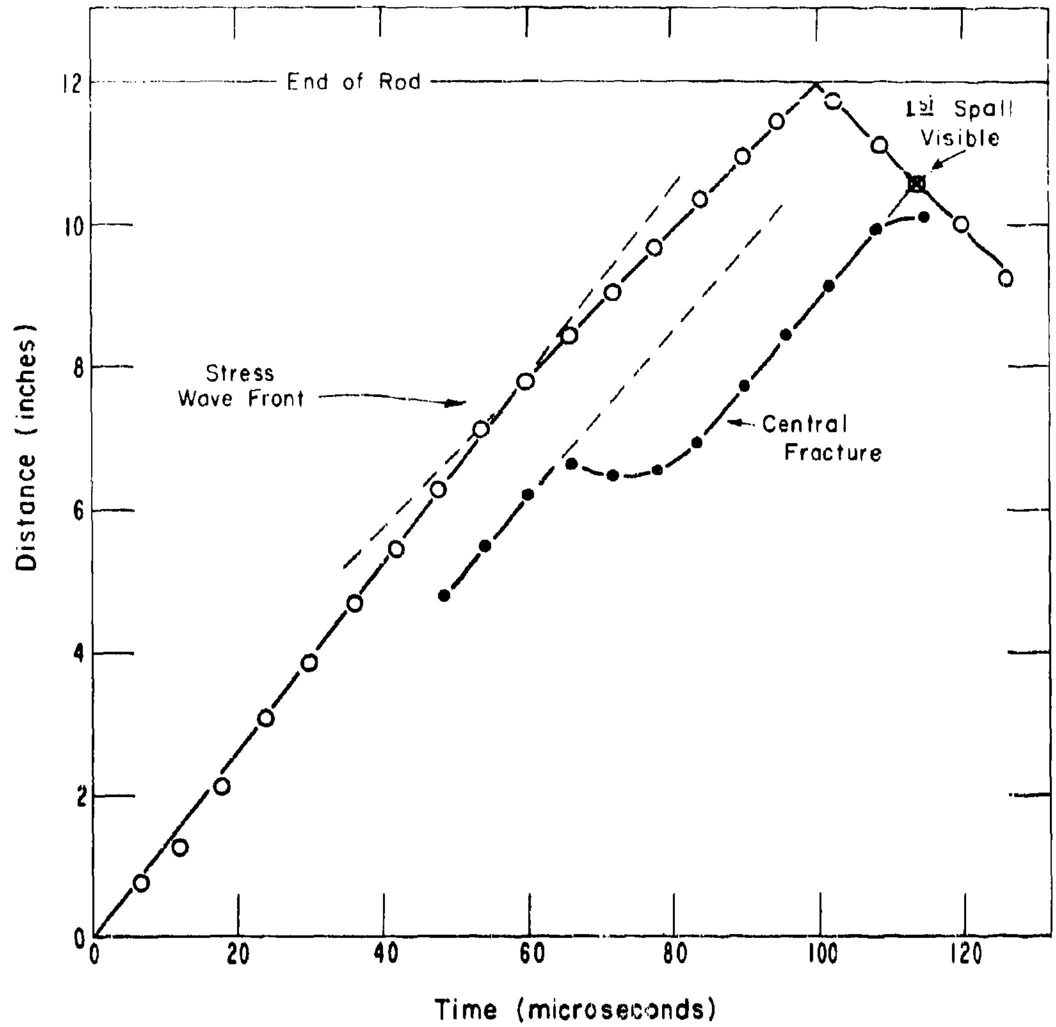

FIG. 9. Distance Versus Time Plots. The graph shows stress wave front and central fracture developed in explosively loaded 3-inch-diameter Plexiglas cylinder.

first 50 μsec. When it comes into view, its lower terminus is moving with a velocity about equal to the dilatational wave velocity. The front of the fracture trails the stress wave front by about 1.5 inches (12 to 13 usec), a distance equal to that which the point G in Fig. 8 lags behind the wave front. Point G, unlike point F, maintains a fixed position with respect to the wave front. It is the point at which the convergence as well as the intensity of the converging release or expansion wave is a maximum. The fracture continues to form at this velocity for a few more microseconds and then suddenly stops when it has reached a distance of about 6.5 inches from the top end of the cylinder. This point is the lower terminus of the fractured plug and is also at about the point where the stress wave front undergoes its decrease in velocity. At this point, the release wave is too weak to produce the stress gradients needed to cause fracturing. By now the region AFB (Fig. 8) has essentially disappeared and the whole cross section of the region up to the point H possesses lateral as well as longitudinal motion.

The fracture curve now assumes a slight negative slope, approximately 1,000 ft/sec, which persists for 10 to 15 μsec. This reverse motion could hardly represent healing of the central fracture. More likely it is motion associated with the expansion wave which might be expected to be retrograde as well as lateral in the region AHBF.

The fracture then starts forward again, moving with a velocity about equal to the rod wave velocity. Presumably, the renewed fracturing is due to the arrival of the converging shear wave AHB that is drawn along behind the longitudinal rod wave. Tensile stresses associated with the converging shear wave are a maximum at point H, which is constrained to move down the cylinder first at the dilatational wave velocity and then the rod wave velocity. For a 3-inch-diameter Plexiglas cylinder, point H will lie 1.5 inches above point G, accounting for the 15 μsec pause occurring as the fracturing process transfers from its association with the expansion wave to its association with the shear wave. Thus, it appears that the central fractures that carve out the plug (A to C in Fig. 5) are caused by convergence of the longitudinal expansion wave, whereas the fractured region (C to F in Fig. 5) which lies further down the cylinder is caused by convergence of the shear wave. The appearances of the two fractured areas are substantially different.

It is apparent from the curve of Fig. 9 that it is possible to observe the reflection of the wave at the lower end of the cylinder and movement of the wave back along it. The small spall in a highly localized region along the axis, about 1 1/2 inches from the far end, appears to have been formed at the time the reflected wave reached the converging shear wave.

SUMMARY

The series of events associated with the transformation of a dilatational wave into a rod wave have been observed using high-speed photography for impulsive end-loading of a solid circular cylinder. Two principal processes extract energy and momentum from the original dilatational wave. One is a converging tensile dilatational wave which follows immediately behind the ongoing compressive dilatational wave; the other is a converging shear wave that is drawn along behind the parent compressional wave. Rather high tensile stresses appear to develop within the tensile wave even though it cannot develop a coherent wave front. The tensile wave, by imparting lateral momentum to rod elements, reduces the velocity with which the longitudinal wave moves forward, roughly in the ratio

$$[E/(2\lambda + G)]^{1/2}$$

where E is Young's modulus and λ and G are Lamé's elastic constants. The advancing tensile disturbance drags behind a shear wave which was cospawned with it to satisfy boundary conditions. Thus, most of the energy of the original wave is soon moving down the rod with a velocity very nearly equal to the familiar rod velocity

$$[E/\rho]^{1/2}$$

rather than the body wave velocity

$$[(2\lambda + G)/\rho]^{1/2}$$

The transformation is fairly well accomplished by the time the original wave has moved two to three diameters down the cylinder.

Quite intense loading was used in the present tests, resulting in much of the momentum of the original blow being lost through shattering of the top end of the cylinder. The most intense portion of this fracturing was caused by the converging tensile wave although fracturing generated by the converging shear wave was also clearly evident.

ACKNOWLEDGEMENT

The author wishes to acknowledge the fine professional effort of Mr. R. Gallup and Mr. D. J. Fischer who were responsible for the high-speed photographic coverage showing the behavior of the explosively loaded lucite rods.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Weapons Center China Lake, California 93555	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP
3. REPORT TITLE MECHANICS OF WAVE BEHAVIOR IN EXPLOSIVELY LOADED ROD	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Research Report	
5. AUTHOR(S) (First name, middle initial, last name) John S. Rinehart	
6. REPORT DATE December 1970	7a. TOTAL NO. OF PAGES: 18 7b. NO. OF REFS: none
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. A35-350/216/70 F17353501 d.	9a. ORIGINATOR'S REPORT NUMBER(S) NWC TP 5059 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
10. DISTRIBUTION STATEMENT EACH TRANSMITTAL OF THIS DOCUMENT OUTSIDE THE AGENCIES OF THE U.S. GOVERNMENT MUST HAVE PRIOR APPROVAL OF THE NAVAL WEAPONS CENTER.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Air Systems Command Department of the Navy Washington, D. C. 20360

13. ABSTRACT

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fracture Stress waves High-speed photography Plexiglas rods						

ABSTRACT CARD

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

NWC TP 5059

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

NWC TP 5059

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

NWC TP 5059

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

ABSTRACT CARD

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

Naval Weapons Center
Mechanics of Wave Behavior in Explosively Loaded Rod, by John S. Rinehart, ESSA Research Laboratories. China Lake, Calif., NWC, December 1970. 18 pp. (NWC TP 5059, publication UNCLASSIFIED.)

High-speed photography has been used to observe and define the pattern of stresses generated by an explosive charge detonated on the end of a right circular cylinder. It was found that the internally convex cylindrical surface transforms and focuses the

(Over)
1 card, 8 copies

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

NWC TP 5059

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

NWC TP 5059

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.

NWC TP 5059

energy of the blow first in the form of a converging tensile wave which is followed shortly by a similarly converging shear wave. Damage is successively wrought by the two converging waves which arrive one after the other; the damage being due to the shear wave extending further down the cylinder. The diameter of the cylinder regulates the extent of the damage, limiting severe damage to the first three diameters of length. Within another diameter or so of length, the original dilatational wave is essentially transformed into a rod wave.